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LIFE CYCLE IMPACT ASSESSMENT (LCIA)

Comparison of different normalised LCIA results and their feasibility in communication

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Abstract
Purpose The purpose of this study was to answer the following three questions: (1) What are the reference values of normalisation for Finnish production and Finnish consumption and how do they differ from the European reference values?, (2) How do these differences influence the interpretation of normalised LCIA results?, and (3) How can normalised LCIA results be made more comprehensible to non-LCA experts with the help of communication material?
Methods Finnish reference values for normalisation were calculated on the basis of the Finnish environmentally extended input–output model and ReCiPe LCIA method. The influence of different normalised results on the interpretation of LCIA was assessed based on an LCA study of print products. LCA communication material (product-specific fact sheets) was developed by organising workshops and interviews with stakeholders in the paper and printing industry.
Results and discussion A comparison of the production based Finnish reference values to the European reference values shows that Finland contributes roughly 1 % to the European values in all impact categories except in the fossil depletion category where the contribution is 3 %. The order of magnitude of the impact categories varies depending on the reference system used for normalisation, which influences the interpretation of LCIA results. The normalised results were made more comprehensible by developing fact sheets including background information and guidance for interpretation of the LCIA results.
Conclusions The interpreter of normalised LCIA results does not usually have the information to estimate how the chosen reference system influences the results. A sensitivity analysis with different reference values may help to highlight this effect. When communicating to non-LCA-practitioners, LCIA results need to be connected to a wider context, which can be achieved by using normalisation to give an idea of the order of magnitude of the results. However, the harmfulness of the impact categories in relation to each other cannot be judged on the basis of the normalised results, which seems to be a difficult concept for non-LCA-practitioners to understand.

Keywords Communication · LCA · Life cycle assessment · LCIA · Life cycle impact assessment · Normalisation · Print product

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1 Introduction

1.1 Communicating LCA results

The role of sustainable production and consumption has been emphasized as a means for minimizing environmental hazards and moving towards more sustainable development (Munasinghe 2010; European Commission 2008). Due to increasing public interest in the environmental impacts of consumption, there is a growing need for environmental information among different industrial actors.

According to ISO 14063 (2006), environmental communication can be defined as “a process that an organization

conducts to provide and obtain information, and to engage in dialogue with internal and external interested parties to encourage a shared understanding of environmental issues, aspects and performance." As a whole, environmental and sustainability communication is a process that requires more and more input from companies (Pihkola et al. 2010a; Munasinghe 2010; Fet et al. 2009).

When considering the general demands and guidelines related to the type and quality of environmental communication, the information should be clear and understandable for the recipient, it should be based on facts (ISO 14063; ISO 26000 2010) and preferably cover the whole life cycle of the product (ISO 14025 2006; European Commission 2003). The results of a life cycle assessment (LCA) study can be used to support decision making in industry, and to provide fact based information for stakeholder communication. However, the focus of LCA studies is more often on the development of LCA methodologies and tools, while the use of LCA-based information by companies (e.g. for communication purposes) has not received much attention (Molina-Murillo and Smith 2009).

Although life cycle thinking is a relatively well-known approach, the use of LCA-based information by LCA non-experts can be challenging (Nissinen et al. 2007). LCA studies provide detailed information on the emissions and environmental impacts of products, but a certain level of expertise in the processes covered, environmental issues and LCA is often required in order to analyse the results and their importance. LCA practitioners have a very challenging role both in performing the LCA study and in translating the complex LCA results into more digestible inputs for the decision making process. In addition to specialized terminology, different actors in product value chains may have difficulties understanding the overall life cycle of the product their operations are connected to. Especially background processes, such as energy, chemicals and raw material production, can be difficult to identify. For example, it may be difficult for a printing company to identify the connection of their book products to the production of chemicals needed in paper manufacturing.

A life cycle impact assessment (LCIA) framework includes six phases: selection of impact categories, classification, characterisation, normalisation, grouping and weighting (ISO 14040 2006; ISO 14044 2006). According to ISO standards, characterisation, based on scientifically justified factors, is considered the last mandatory step of an LCIA. In characterisation, different environmental interventions (emissions, resource extractions, and land use) are aggregated to impact category indicator results on the basis of the relevant environmental processes. Impact scores are expressed in units, which differ between impact categories. From a stakeholder's perspective, impact category indicator results are more manageable than inventory results but due to their proxy characteristics they are difficult to interpret. In order to obtain a more comprehensive view of impact category indicator results, normalisation can be conducted.

1.2 Normalisation in LCIA

The aim of normalisation is to place impact category indicator results in an adequate environmental context (inter alia Wegener Sleeswijk et al. 2008; Laurent et al. 2011). Additionally, normalisation is used to check for inconsistencies, to provide and communicate information on the relative significance of the indicator results and to prepare for additional procedures, such as grouping, weighting or life cycle interpretation (Heijungs et al. 2007; Seppälä 2007; Wegener Sleeswijk et al. 2008).

Two separate normalisation techniques exist: (1) external normalisation or determination of relative contribution and (2) case-specific or internal normalisation. The following equation is adequate for both approaches (Finnveden et al. 2002):

$$N_i = S_i \div R_i$$

where i is the impact category, N is the normalised results, S is the product system results, and R is the reference value.

The goal of external normalisation is to put case-specific LCIA results in a wider context. Hence, it requires external information of the contributors within the reference region. In internal normalisation, data from two different options within the same LCA study are referenced to each other. Internal normalisation is primarily seen as an operational prerequisite to weighting (Finnveden et al. 2002). Weighting is not a focus of this paper; hence, internal normalisation is not dealt with further here.

A reference system for external normalisation can be chosen on the basis of various dimensions: system basis (e.g. a region, an economic sector), system treatment (e.g. in-region activities), spatial scaling (e.g. nation, continent), temporal scaling (e.g. per year) and additional magnitude scaling (e.g. per capita). Regionally defined reference values, based on geographically restricted areas, are most commonly used (Laurent et al. 2011; Lautier et al. 2010; Wegener Sleeswijk et al. 2008). However, reference values can also be defined for regional consumption (Breedveld et al. 1999) and such values are based on the impacts generated by the materials and products consumed in a region, no matter whether they are imported or produced in the region itself. For regionally undefined product systems, the use of global reference values is recommended by Huijbregts et al. (2003). If, however, the majority of the emissions and extractions of a product system are located in a specific country or region such as Europe, the reference values for these regions may be preferable (Huijbregts et al. 2003). It is

important to note that characterization for the impact category indicator results of the reference systems must be consistent with the characterization for the indicator results of the product systems (Finnveden et al. 2002; Laurent et al. 2011; Seppälä and Hämäläinen 2001). In this paper, the focus is on the interpretation of external normalisation results, in which spatial and temporal scaling and scaling per capita were used.

Normalisation makes it possible to translate the abstract impact scores of different impact categories into a more understandable and presentable form, i.e. showing the magnitude of each impact of the product relative to a reference situation, the reference situation being, e.g. the environmental impacts of an economic system that the product life cycle is considered to be part of (Wegener Sleeswijk et al. 2008). The fact that the normalisation results are relative values for each impact score makes it easier to make comparisons between impact scores of different impact categories (Norris 2001; Wegener Sleeswijk et al. 2008). In order to use normalised values for the ranking of impact categories, the interpretation should be carried out so that the impact category indicator results caused by a reference system have equal significance in terms of environmental problems (Seppälä 2007; Seppälä and Hämäläinen 2001). This can also be interpreted that a weighting has been done with the assumption that all environmental problems are equally significant.

1.3 Aims of the study

The aim of this study was to answer the following three questions: (1) What are the reference values for Finnish production and Finnish consumption and how do they differ from the European reference values?, (2) How do these differences influence the interpretation of the normalised LCIA results?, and (3) How can normalised LCIA results be made more comprehensible to non-LCA experts with the help of communication material?

2 Material and methods

2.1 General description

We compare three types of reference values in this paper: European values (EU_{25+3}), Finnish consumption (FI_{cons}) values and Finnish production (FI_{prod}) values. The two first ones were originally used in our case study on print products. We produced the additional reference values for Finnish production (FI_{prod}) for the purposes of this paper in order to perform comparisons between the Finnish and the European reference values and their influence on the normalised results.

The influence of using the different reference values was tested in the case study of print products, in which LCAs were conducted for newspapers and photo books. The characterised impact category results were normalised in order to facilitate the interpretation of the LCIA results. In normalisation, two different reference values were used: European (EU_{25+3}) and Finnish consumption (FI_{cons}) values. These normalised results were applied to develop communication material, in the form of ‘fact sheets’, in which the environmental impacts of the products were presented in a comprehensible form (Pihkola et al. 2010a). The development process was conducted iteratively in close cooperation with stakeholders from the paper and printing industry. The stakeholders included both Finnish and European representatives and the communication material was intended to be used both in Finland and in other European countries. Two workshops and 13 themed interviews were organized to obtain stakeholders’ opinions on the needs for additional information. Finally, they had the opportunity to comment on the comprehensibility of the normalised results and the fact sheet material developed.

The feasibility of the normalised LCIA results for communication purposes was analysed using the results from the interviews, workshops and other material produced in the case study for print products. The objective of the case study was to identify the most relevant challenges related to the communication of environmental information and to gather ideas and tools for improving communication within the value chain of print products.

2.2 Reference values

The ReCiPe reference values are based on an LCA study of the global and European economic systems in the year 2000 (Wegener Sleeswijk et al. 2008; LCA ReCiPe Midpoint Normalisation 2000 (2010). Wegener Sleeswijk et al. (2008) assessed economies on two levels: the world and Europe. Europe consisted of 28 European countries, consisting of the 25 countries of the European Union in 2006 (including Finland) supplemented with Iceland, Norway and Switzerland (referred to as EU_{25+3}). Data on environmental releases and extractions are most often not available in the form or at the geographical scale that exactly corresponds to the specific needs of an LCA normalisation study. Therefore, data estimates had to be used for generating the European reference values (Wegener Sleeswijk et al. 2008).

The overall environmental impacts for Finland were assessed on the basis of emissions obtained from the Finnish environmentally extended input–output (EE-IO) model ENVIMAT (Seppälä et al. 2009; Koskela et al. 2011; Seppälä et al. 2011). We calculated two sets of reference values on the basis of the ENVIMAT model data for the year 2005. For the first set of Finnish reference values, we

considered the impacts caused by the consumption by Finnish people (this is further referred to as FI_{cons}). This was due to the fact that both our case products, newspapers and photo books, are consumer products by nature. This approach includes imported goods and materials as well as the related environmental impacts, but excludes exported goods (Seppälä et al. 2009; Koskela et al. 2011). We selected actual individual consumption (AIC) as a basis for consumption values. It includes consumer goods and services purchased by households, in addition to services provided by non-profit institutions and the government for individual consumption, for example, health and education services. In other words, AIC covers all goods and services actually consumed by households.

For the second set, we assessed the impacts caused by all the activities located in the geographical area of Finland (this is further referred to as FI_{prod}). The domestic activities need imported fuels and minerals, which have been taken into account in the FI_{prod} reference values. The most dominant industrial sectors in Finland are the pulp and paper industry and the metals industry, which both export the majority of their production. Differences between the three reference values were analysed by identifying and comparing the main contributors to a given impact category.

2.3 LCAs of case products

During the life cycle inventory of newspapers and photo books, data were collected both from databases and from the value chain actors (Pihkola et al. 2010b). The life cycle of the newspaper included life cycle stages from raw material manufacturing until the disposal of the read newspaper. The life cycle of the photo book excluded the end-of-life phases. The manufacturing of both printed products takes place in Finland, whereas some of the upstream processes take place abroad (=imported auxiliary materials). The functional unit used for both product systems was 1,000 kg of the product. Annual-level input and output data from printing and related processes were collected between 2006 and 2009. The data can be considered as relevant examples from the printing industry, indicating the current situation and general development trends (Pihkola et al. 2010b).

In the LCIA phase, the midpoint-level assessment of the ReCiPe Mid/Endpoint method was used (version 1.05 July 2010) (Goedkoop et al. 2009), for converting emissions of substances with adverse environmental impacts and extractions of natural resources into impact category indicator results for seven impact categories (Table 1). The impact categories related to either human toxicity or ecotoxicity were left out primarily due to the incompleteness of inventory data. Inventory data from generic databases included toxic emissions, but the process-specific data for the core processes did not.

2.4 Development of communication material

The iterative process of developing communication material in the case study of print products included two workshops and 13 themed interviews. Altogether, 31 persons representing different industrial sectors of the value chain and different tasks within the participating companies (such as

Table 1 Impact categories included in the LCIA of case products and environmental pressures included in the assessment of the Finnish reference values

Emissions to air	Emissions to water	Extraction of resources	Impact categories considered for print products
CO_2-foss.	P-total	Aluminium	Climate change (CC)
CH_4		Chromium	Terrestrial acidification (TA)
N_2O		Cobalt	Freshwater eutrophication (FE)
SO_2		Copper	Photochemical oxidant formation (POF)
NO_x		Iron	
NH_3		Lead	Particulate matter formation (PMF)
NMVOC		Manganese	Fossil depletion (FD)
CO		Molybdenum	Metal depletion (MD)
PM_{10}		Nickel	
C_6H_6		Silver	
		Tin	
		Zinc	
		Oil	
		Coal	
		Brown coal	
		Natural gas	
		Peat	

environmental managers or marketing and sales personnel actors) contributed to the process. The communication material was modified and updated according to the comments and feedback received. (Pihkola et al. 2010a).

The existing tools available for communicating the LCA results of paper-based print products, such as the Nordic Ecolabel (Nordic 2012), the EU Ecolabel (EU Ecolabel 2012) and the environmental product declarations (EPD, Environmental Product 2012) were recognised in the process, but their deficiencies from a communication point of view were also identified. The labels as such do not provide information about the environmental aspects of a product. The EPD system, for use in business to business communication, especially for purchasing and procurement situations was considered informative, but not suitable in our case study due to, e.g. the heterogeneity of the stakeholders in the value chain (Pihkola et al. 2010a).

Therefore, we decided to develop product-specific fact sheets to communicate the main results of the print product LCAs. We also intended the fact sheets to be used as educational material targeted at the company’s own personnel and direct customers in order to increase understanding of the research methods and critical issues in interpretation of LCA results, and thereby to activate communication. Based on the empiric data from the interviews and the workshops there was a strong need for such material (Pihkola et al. 2010a). Since carbon footprint was a topical issue for the print industry during the discussions, it was decided to prepare additional versions of the fact sheets focusing only on the carbon footprint and climate change impacts of the case products. However, the carbon footprint fact sheets are not on the focus of this paper.

The first versions of the fact sheets were formulated based on the ideas generated in a researcher workshop. They included the normalised LCIA results presented with information on both the LCA methodology, and on the environmental impacts as well as possibilities to reduce them.

The drafts of the fact sheets were then discussed with industry representatives and other interested parties in another workshop and in interviews. The interviews brought up several challenges relating to the communication of environmental information, such as, among others: to present the conclusions concisely and interestingly, but nonetheless including detailed information and the significance of the results in a wider perspective (Pihkola et al. 2010a). These same issues and the need to give guidance to the reader in order to interpret the LCIA results were also raised in the workshops. The finalized versions of the fact sheets for a Finnish newspaper are included as supplementary material of the online version of this paper.

In the development process, one of the main challenges was to give an idea of the order of magnitude of the LCIA results in a wider context and a baseline which the recipients could comprehend. In our study, the order of magnitude was provided using the normalisation approach. In order to bring the system closer to the reader we compared the environmental impacts of 1 tonne of product to those of a yearly subscription of newspaper or of 100 photo books.

3 Results and discussion

3.1 Comparison of the European and Finnish reference values

A comparison of the production based Finnish reference values to the European reference values shows that Finland's contribution (FI_{prod}) to the European impact category results is around 1 % (Table 2). The only exception is the fossil depletion (FD) impact category, where Finland contributes 3 %. Our understanding is that the Finnish contribution in FD rises higher than in other impact categories because two energy intensive industrial sectors, namely metals industry and pulp and paper industry, dominate the Finnish production.

The per capita reference values are in general higher for FI_{prod} than for both EU_{25+3} and FI_{cons} (Table 3). In the climate change (CC) impact category the difference is smallest between EU_{25+3} and FI_{prod} whereas it is largest between FI_{prod} and FI_{cons} (see Table 3). In the CC category, the most significant difference between the EU_{25+3} and FI_{prod} values is in the contribution of CO_2 emissions, which in the EU_{25+3} is 77 % whereas in FI_{prod} it is 83 % (Table 4). This reflects the previously mentioned fact that Finnish industrial activities are dominated by two energy intensive sectors: the pulp and paper industry and the metals industry. This is also one explanation for the higher values for CC in FI_{prod} than in FI_{cons}. Additionally, in the FD impact category results, the FI_{prod} per capita value is higher than both EU_{25+3} per capita value and FI_{cons} per capita value (see Tables 2 and 3), due to the above-mentioned reason.

Acidification has had a high priority in Finnish environmental policy since the 1980s. Finnish industries have been required to invest in desulphurisation plants and emissions of SO_2 have reduced significantly (Air Pollutant Emissions in Finland 2011). This is reflected in the smaller contribution of SO_2 to the terrestrial acidification (TA) value for FI_{prod} (28 %) than for the EU_{25+3} (31 %) (see Table 4). The higher contribution of SO_2 in the FI_{cons} value than in the FI_{prod} value may be due to the differences in the technology used for the imports, i.e. desulphurization technology is not used as widely abroad as in Finland. In Finland, NO_x-emissions (originating, e.g. in transportation) have a bigger role in acidification than in the EU, although the characterization factor is lower for NO_x (characterization factor=0.56) than for SO_2 (characterization factor=1). In contrast, the

Table 2 Reference values for Europe (EU_{25+3}, Wegener Sleeswijk et al. 2008) and Finland (FI_{prod} and FI_{cons}) for selected impact categories

Impact category	Unit	EU_{25+3}, total	FI_{prod} total	FI_{cons}, total	EU_{25+3}, per capita[a]	FI_{prod}, per capita[b]	FI_{cons}, per capita
CC (TH 100 years)[c]	kg CO_2-eq.	5.21E+12	6.89E+10	5.18E+10	1.12E+04	1.29E+04	9.68E+03
TA (TH 100 years)	kg SO_2-eq.	2.49E+10	2.59E+08	2.35E+08	3.44E+01	4.84E+01	4.40E+01
FE	kg P-eq. (to fresh water)	3.47E+08	3.82E+06	2.91E+06	4.15E-01	7.15E-01	5.44E-01
POF	kg NMVOC-eq.	2.64E+10	3.52E+08	2.97E+08	5.31E+01	6.57E+01	5.56E+01
PMF	kgPM_{10}-eq.	8.12E+09	1.09E+08	9.67E+07	1.49E+01	2.03E+01	1.81E+01
MD	kg Fe eq.	-	3.38E+10	4.87E+09	7.13E+02[d]	6.32E+03	9.10E+02
FD	kg oil eq.	7.23E+11	2.49E+10	1.40E+10	1.66E+03	4.66E+03	2.62E+03

[a] Population of EU_{25+3}: 464,551,510 (based on the climate change total and per capita values)

[b] Population of Finland: 5,351,427

[c] TH= time horizon

[d] From LCA ReCiPe Midpoint Normalisation 2000 (2010)

contribution of ammonia in terrestrial acidification is higher in the EU than in Finland. The role of ammonia emissions are emphasized by the high characterization factor in ReCiPe (2.45). Of the Finnish total ammonia emissions, 78 % originate from livestock farming.

In ReCiPe, the freshwater eutrophication (FE) category includes only phosphorus emissions. The per capita values are lower for Europe than for Finland. A comparison of the two Finnish values shows that the FI_{prod} values are slightly higher than the FI_{cons} values. The role of agriculture is significant in the Finnish FE impacts because 71 % of the total phosphorus emissions to water originate from agriculture. The share of the pulp and paper sector is 4 % for both phosphorus emissions.

In the metal depletion (MD) impact category the FI_{prod} per capita value is significantly higher than the EU_{25+3} per capita value. The reason for this is the strong Finnish metal industry that uses imported metals. In addition to this, the mining industry is a fast growing sector in Finland, thus the MD impacts will increase in the future. The contributions of different metals to the EU_{25+3} were not analysed in Wegener Sleeswijk et al. (2008), thus a comparison between the EU and Finland cannot be performed (Table 5). The two Finnish values can, however, be compared and it shows that copper dominates for both FI_{prod} and FI_{cons} (with 66 and 29 %, respectively).

The differences between the Finnish and European per capita reference values can also be reasoned by differences in the accuracy and extensiveness of the emissions data behind the reference values. The Finnish values are based on an EE-IO analysis of the Finnish economy. In the EE-IO model, the emissions were compiled for each industry from the national emission inventories or calculated on the basis of activity information (Seppälä et al. 2009). For the ReCiPe reference values for Europe, on the other hand, the emissions of several substances are based on estimations and calculations (Wegener Sleeswijk et al. 2008). According to Laurent et al. (2011), the results for conventional impact categories (included in our assessment) are generally reliable due to the considerable experience of reporting inventories for the associated emissions both at the national and European levels, and the established characterization models. When updating normalisation references, changes in these categories mainly result from changes in the substance emissions or changes in the size of the population (Laurent et al. 2011).

Table 3 Relationship of the reference values for the EU and for Finland

Impact category	FI_{prod}, per capita/ EU_{25+3}, per capita	FI_{cons}, per capita/ FI_{prod}, per capita
CC (TH 100 years)[a]	1.15	0.75
TA (TH 100 years)	1.41	0.91
FE	1.72	0.76
POF	1.24	0.85
PMF	1.36	0.89
MD	8.85	0.14
FD	2.8	0.56

[a] TH= time horizon

3.2 Normalised results for the case products

We used normalisation as a means to present the print product LCIA results with more comprehensible values than the impact category indicator scores and this also made it possible to make comparisons between the contributions of impact categories to the reference system. Normalised life cycle impact assessment results show the contribution of the case product system's environmental impacts to the impacts of the reference system. Since weighting between impact categories was not done, the normalised impact category results can be considered to be of

Table 4 Contributions of individual emissions to reference values for $EU_{25+3}/FI_{prod}/FI_{cons}$: emission-related impact categories (adapted from Wegener Sleeswijk et al. 2008)

Substance	Emission compartment	CC (TH 100 years)	TA (EU_{25+3}:TH 500 years, Finland: TH 100 years)	FE	POF	PMF
CO_2	Air	77/83/79				
CH_4	Air	10/10/11			</1/1	
N_2O	Air	</8/10[a]				
NO_x	Air		30/39/36		42/51/51	32/36/34
SO_2	Air		31/28/33		</2/2	22/13/16
NH_3, air	Air		3/34/31			14/10/10
NH_3 (total)	Air, agricultural soil		40[b]			
P-total	Water			66/100/100		
NMVOC	Air				42/39/39	
CO	Air				</7/7	
Benzene	Air				</1/1	
PM_{10}	Air					31/40/40
P-total	Agricultural soil			34[b]		

[a] Note that from the background data concerning the EU_{25+3} reference values, only interventions contributing to a joint share of at least 75 % of the total result are listed. < The contribution of the emissions/intervention is less than this. – the emission is missing

[b] Only in Wegener Sleeswijk et al. 2008

equal importance from the perspective of environmental protection within each region considered in the normalisation reference calculations and the harmfulness of one category over another cannot be evaluated.

In the English print product communication material we used the environmental impacts of a European as the reference basis, whereas in the Finnish material we used the environmental impacts produced by the consumption of a Finn. The different normalisation bases were used, since the Finnish value chain actors were interested in relating the results to Finnish consumption. However, the value chains reach across the borders of Finland, and hence a broader European perspective was obtained using the EU_{25+3} reference values.

Table 5 Contributions of individual interventions to reference values for EU_{23+5}/ FI_{prod} /FI_{cons}: non-emission-related impact categories (adapted from Wegener Sleeswijk et al. 2008)

Substance extracted	Intervention type	FD	MD
Copper	MD		n.a./66/29
Chromium			n.a./15 /23
Iron			n.a./13 /16
Nickel			n.a./4/7
Zinc			n.a./0.2/2
Crude oil	FD	38/65/56	
Natural gas		37/16/22	
Hard coal		14/10/13	
Lignite		11[a]	
Peat		–/9/8	

– the intervention is missing; *n.a.* contribution of the intervention not assessed

[a] Only in Wegener Sleeswijk et al. (2008)

The use of different reference values produces slightly different LCIA results for the case products newspapers and photo books (Fig. 1). In each normalisation approach, the normalised impact category result for CC was given a value of 100 and the other impact category results were proportioned to this (see Fig. 1). Hence, the impact category results reflect the relative differences between impact categories relative to a fixed CC result. However, the profiles produced by different reference values should not be compared, but instead the relativity between different impact category results within each normalisation approach should be considered. Relative to a higher reference value, the contribution of the studied system is smaller than if the system is compared to a lower reference value. For example, the Finnish production structure (i.e. dominant metal industry) produces a high MD per capita reference value for Finland in relation to CC (see Tables 2 and 3). In the EU, the MD per capita reference value is lower resulting in a lower relative value compared to CC than for Finland. Hence, the contribution of the product system to MD is higher in relation to the EU reference values than in relation to the Finnish reference values.

Generally, normalised LCIA results are used to help prioritize measures for mitigating the environmental impacts

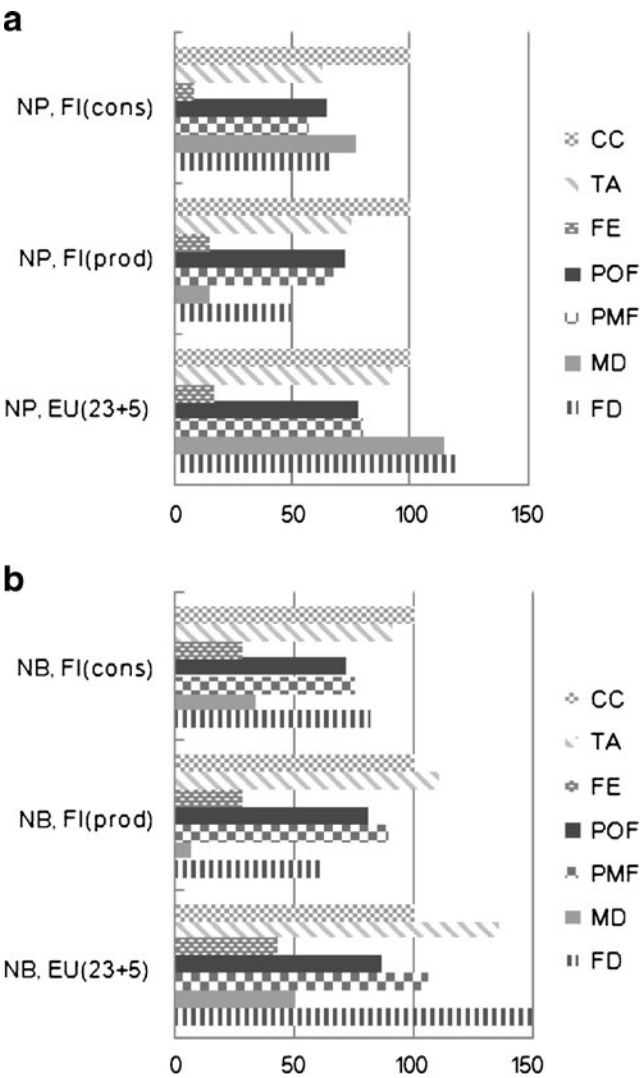

Fig. 1 a and b. Normalised LCIA results of 1 tonne of newspaper (NP) and 1 tonne of digital photo books (PB). The CC result was set to the value of 100 and the other impact category results are illustrated in relation to CC. Normalisation performed with three different reference values: *FI(cons)* Finland, consumption based, per capita; *FI(prod)* Finland, geographical area based, per capita; *EU(23+5)* ReCiPe reference values for EU, per capita. Impact categories studied: *CC* climate change, *TA* terrestrial acidification, *FE* freshwater eutrophication, *POF* photochemical oxidant formation, *PMF* particulate matter formation, *MD* metal depletion, *FD* fossil depletion

of the processes or systems. Our results illustrate that applying different reference values produces slightly different emphasis for these measures. For example, depending on the reference system used for normalisation the order of magnitude of the impact categories varies. As shown in Table 6, CC is in the top (position 1 or 2) using Finnish reference values, but when using European reference values, the magnitude of CC is third or fourth (see Table 6). For our case products, some of the other impact categories (e.g. FE) get more consistent orders of magnitude using the Finnish and European reference values.

The orders of magnitude in Table 6 can only be provided, if the interpreter understands and accepts that the impacts in all categories are considered equally harmful to the environment. The normalisation results show the magnitude of each impact related to impacts of a reference system and the order of magnitude shows whether the magnitude of the impact in, e.g. CC category is higher than in, e.g. TA category.

As our analysis indicates, different normalisation bases provide different interpretations of LCIA results and it is therefore very important to choose the most feasible and consistent reference values for normalisation. Also Lautier et al. (2010) have concluded that normalised profiles are highly dependent on the selected reference due to differences in the industrial and economic activities. Especially when the normalised results are used to increase the usability of the results for communication as well as to make the results more comprehensible, an additional effort has to be made to choose appropriate reference values. Our results also support the approach of ISO standards in that characterization should be the last mandatory step of life cycle impact assessment since normalisation brings subjectivity into the results and their interpretation. Various boundaries have been used for reference systems (e.g. Breedveld et al. 1999). When choosing the reference system for normalisation, it is important that for each impact category equal boundaries are used.

3.3 Communication of LCIA results

Previous LCA studies have recognised that there is always a risk of either oversimplifying LCA results or presenting them to the recipient with an excessive amount of detailed information (see e.g. Molina-Murillo and Smith 2009; Nissinen et al. 2007). However, providing enough information about the assumptions and system boundaries used in the study is essential for the interpretation of the results (Pihkola et al. 2010b). In our fact sheets, we aimed to find a good balance between oversimplifying and overloading by highlighting relevant and applicable information.

The finalized fact sheet for each print product composed of four pages. At the core of the fact sheets were figures presenting the system boundaries and the normalised LCIA results of the studied products divided by (a) life cycle phases and (b) environmental impact categories. The results were presented for 1 tonne of product and for a yearly subscription of a newspaper or for 100 photo books. The five text chapters provided: (a) the main principles of LCA, (b) LCIAs of a Finnish newspapers/photo books, (c) identification of the relative contributions of life cycle phases to the overall environmental impacts, (d) recommendations for reducing environmental impacts, and (e) general information on print products (annual production, consumption patterns). Two info boxes described the assumptions made

Table 6 Order of magnitude of the impact category contributions of the newspaper and photo book product systems to the respective impacts of the three reference systems used for normalisation, 1=highest and 7=lowest contribution

Impact category	Newspaper			Photobook		
	FI_{cons}	FI_{prod}	EU_{25+3}	FI_{cons}	FI_{prod}	EU_{25+3}
CC	1	1	3	1	2	4
TA	5	2	4	2	1	2
FE	7	7	7	7	6	7
POF	4	3	6	5	4	5
PMF	6	4	5	4	3	3
MD	2	6	2	6	7	6
FD	3	5	1	3	5	1

in modelling the product system and the environmental impacts included in the assessment (see Lean development with renewable resources (LEADER) 2010). Examples of fact sheets are provided as Electronic Supplementary Material to this paper.

Overall feedback from the stakeholders suggested that the way the fact sheets covered the whole life cycle of the products including a clarification of terms and presentation of the results in proportion to other activities was appreciated. However, the first impression was that the fact sheets were still laborious to read and difficult to understand. Based on the interviews, this was due to the complexity of both research method and environmental impacts themselves. Understanding the connections between the emissions and environmental impact categories were considered challenging. This finding was supported by the observation that the fact sheets that were restricted to the carbon footprint results of the studied products were considered very informative and easy to read. However, in general, the stakeholders agreed that the fact sheets responded to the demand for information and educational material for use, e.g. in internal meetings and training as well as background information for sales personnel and customers (Kariniemi et al. 2011).

Discussions with stakeholders indicated that the use of normalisation can be useful in putting the results into a wider perspective. However, due to the challenges of understanding the LCA methodology, simple but comprehensible explanations are required to help the interpretation. The stakeholders preferred the use of the Finnish consumption-based reference value in the Finnish fact sheets, since this way they got a better view of the order of magnitude of the results. The Finnish consumption values are not as familiar for foreigners, hence the European reference values were chosen for the English fact sheets. Both the reference systems were comprehensible, but the fact that the harmfulness of the impact categories cannot be judged on the basis of the normalised results, was difficult for the stakeholders to grasp. In the case study, the impacts concerning toxicity were not assessed due to inconsistencies in the data; hence these impacts could not be addressed to the stakeholders.

In our case study, we chose to use the ReCiPe methodology for LCIA, since it is based on the latest recommendations given by the LCA community (European Commission Joint Research Center 2010 and 2011). However, the choice of LCIA methodology may have an effect on the outcome of the performance of the products studied. With another methodology, the results may have been somewhat different.

In the print product LCA study, we took one step forward in fulfilling the need for sustainability communication material and refining the presentation of the LCA results into a more easily digestible form. Compared to the existing communication tools used in the print product sector, our approach improved presenting overall picture of the environmental impacts of the studied systems in a compact form. However, a number of communicational needs remain for which the fact sheets are not suited. In particular, the challenges of consumer communication were brought up by stakeholders in many discussions. A study by Molina-Murillo and Smith (2009) indicated that LCA-based information could also be used in consumer communication to increase the credibility of the message among environmentally conscious consumers.

4 Conclusions

In this study, two sets of Finnish reference values (consumption and production based) for normalisation were calculated. The production based values were compared to European reference values showing that Finland contributes roughly 1 % to the European values in all impact categories except in the FD category where the contribution was 3 %.

It is important to choose appropriate reference systems for normalisation, because the use of different reference systems produces a slightly different interpretation of LCIA results. The interpreter of normalised LCIA results

does not usually have the information to estimate how the chosen reference system influences the results. A sensitivity analysis with different reference values may help to highlight this effect.

The biggest challenges of communicating LCA results are related to presenting the results in a simple and comprehensible way, which enables an appropriate interpretation for decision making purposes. Results need to be understood in a wider context and with an idea of their order of magnitude, which can be achieved through normalisation. However, the harmfulness of the impact categories relative to each other cannot be judged on the basis of the normalised results, which seems to be difficult for non-LCA-practitioners to comprehend.

If interpreted correctly, normalised LCIA results are feasible in business to business communication, since they provide information on the contribution of the studied system to the overall environmental impacts of the reference system. This helps to direct the mitigation measures to the relevant environmental problems. Descriptions of the methods and assumptions used are important for supporting the interpretation. However, it is challenging to keep the information simple and scientifically valid at the same time.

Compared to the existing communication tools used in the print product sector, our fact sheet approach improved presenting the overall picture of the environmental impacts of the printed products in a compact form. The next step should be to further develop consumer communication for the LCA results of printed products.

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